We claim:

1. A multi-mode internal combustion engine capable of operating in a plurality of modes for engine operation, comprising:

an engine body;

a combustion chamber formed in the engine body;

an intake air system for delivering intake air to said combustion chamber;

a fuel delivery system mounted on said engine body to deliver a first fuel into said combustion chamber while the engine operates in a homogeneous charge dual fuel transition mode, and to deliver a second fuel into at least one of said intake air system and said combustion chamber when the engine operates in a premixed charge compression ignition mode and in said homogeneous charge dual fuel transition mode; and

a control system adapted to transfer engine operation between said homogeneous charge dual fuel transition mode and said premixed charge compression ignition mode.

2. The engine of claim 1, wherein said fuel delivery system is adapted to deliver said first fuel into said combustion chamber while the engine operates in a diesel mode and said control system is adapted to transfer engine operation between said diesel mode and said homogeneous charge dual fuel transition mode.

3. The engine of claim 2, wherein said control system is adapted to: i) cause said fuel delivery system to deliver a primary quantity of said first fuel into said combustion chamber when in said diesel mode; and ii) when transferring engine operation to said homogeneous charge dual fuel transition mode, cause said fuel delivery system to deliver a quantity of said second fuel into at least one of said intake air system and said combustion chamber while decreasing said primary quantity of said first fuel to maintain engine torque at a substantially constant level and to place the engine in said homogeneous charge dual fuel transition mode.

4. The engine of claim 3, wherein said control system is further adapted to cause said fuel delivery system to decrease said primary quantity of said first fuel while increasing the quantity of said second fuel so that the quantity of said second fuel comprises a substantial portion of the total delivered fuel energy.

5. The engine of claim 4, wherein said control system is further adapted to control a start of combustion in said combustion chamber and adjust said start of combustion to occur prior to delivery of said primary quantity of said first fuel.

6. The engine of claim 4, wherein said control system is further adapted to cause said fuel delivery system to deliver an early pilot quantity of said first fuel prior to a start of combustion in said combustion chamber when in said homogeneous charge dual fuel transition mode.

7. The engine of claim 6, wherein said control system is further adapted to cause said fuel delivery system to increase said early diesel pilot quantity of said first fuel sufficiently to cause the start of combustion to occur prior to the delivery of said primary quantity of said first fuel.

8. The engine of claim 2, wherein said control system is further adapted to cause said fuel delivery system to deliver a post-ignition injection of said first fuel into said combustion chamber after a start of combustion of a premixed charge of said second fuel and air in said combustion chamber when in said premixed charge compression ignition mode to operate the engine in a post premixed ignition injection mode.

9. The engine of claim 2, wherein said control system is further adapted to cause said fuel delivery system to deliver an early pilot quantity of said first fuel prior to a start of combustion of a premixed charge of said second fuel and air in said combustion chamber when in said premixed charge compression ignition mode.

10. The engine of claim 2, wherein said first fuel is one of diesel fuel, kerosene and gasoline and said second fuel is one of natural gas and propane.

11. A method of operating an internal combustion engine in a plurality of modes for engine operation and transferring operation between the plurality of modes, comprising the steps of:

operating the engine in a premixed charge compression mode; and

operating the engine in a homogeneous charge dual fuel transition mode;

transferring engine operation between said homogeneous charge dual fuel transition mode and premixed charge compression ignition mode.

12. The method of claim 11, further including the steps of operating the engine in a diesel mode and operating the engine in said homogeneous charge dual fuel transition mode when transferring engine operation between said diesel mode and said premixed charge compression ignition mode.

13. The method of claim 12, wherein the engine uses only a single fuel for all modes of operation.

14. The method of claim 13, wherein said single fuel is diesel fuel.

15. The method of claim 14, further including the steps operating the engine in a post premixed ignition injection mode, starting the engine in said diesel mode, transferring engine operation to said premixed charge compression ignition mode during a first engine load range, operating the engine in one of said premixed charge compression ignition mode and said post premixed ignition injection mode during a second engine load range, and transferring engine operation from one of said premixed charge compression ignition mode and said post ignition injection mode to said diesel mode for operation during a third engine load range.

16. The method of claim 15, further including the steps of providing said single fuel to a plurality of engine combustion chambers and adjusting an amount of said

single fuel to each of said plurality of combustion chambers to adjust a timing of a start of combustion.

17. The method of claim 15, further including the steps of providing an intake valve for each of a plurality of combustion chambers of the engine and controlling a timing of an opening of each intake valve to control an effective compression ratio for the respective combustion chamber to control a start of combustion.

18. The method of claim 15, further including the step of directing an exhaust gas into at least one of a plurality of combustion chambers to control a start of combustion for the combustion chambers receiving the exhaust gas.

19. The method of claim 12, further including the step of sensing a combustion characteristic, generating a combustion characteristic signal and controlling a start of combustion based on said combustion characteristic signal.

20. The method of claim 12, further including the steps of i) delivering a primary quantity of a first fuel into said combustion chamber when in said diesel mode; and ii) when transferring engine operation to said homogeneous charge dual fuel transition mode, delivering a quantity of a second fuel into at least one of an intake air system and a combustion chamber while decreasing said primary quantity of said first fuel to maintain engine torque at a substantially constant level and to place the engine in said homogeneous charge dual fuel transition mode.

21. The method of claim 20, further including the step of decreasing said primary quantity of said first fuel while increasing the quantity of said second fuel so that the quantity of said second fuel comprises a substantial portion of the total delivered fuel energy.

22. The method of claim 21, further including the step of delivering an early pilot quantity of said first fuel prior to a start of combustion when in said homogeneous charge dual fuel transition mode.

23. The method of claim 22 , further including the step of increasing said early diesel pilot quantity of said first fuel sufficiently to cause the start of combustion to occur prior to the delivery of said primary quantity of said first fuel.

24. The method of claim 12, further including the step of delivering a post-ignition injection of a first fuel into a combustion chamber of the engine after a start of combustion of a premixed charge of a second fuel and air in the combustion chamber when in said premixed charge compression ignition mode to operate the engine in a post premixed ignition injection mode.

25. The method of claim 12, further including the step of delivering an early pilot quantity of a first fuel into a combustion chamber of the engine prior to a start of combustion of a premixed charge of a second fuel and air in said combustion chamber when in said premixed charge compression ignition mode.

26. The method of claim 12, further including the steps of operating the engine in a spark ignition mode and operating the engine in said homogeneous charge dual fuel transition mode when transferring engine operation between said premixed charge compression ignition mode and said spark ignition mode.

27. The method of claim 26, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of fuel for igniting a premixed charge of fuel and air.

28. A multi-mode internal combustion engine capable of operating in a plurality of modes for engine operation, comprising:

an engine body;

a combustion chamber formed in the engine body;

an intake air system for delivering intake air to said combustion chamber;

a fuel delivery system mounted on said engine body to deliver a first fuel into said combustion chamber while the engine operates in a homogeneous charge dual fuel transition mode, and to deliver a second fuel into at least one of said intake air system and said combustion chamber when the engine operates in a premixed charge

compression ignition mode, in a spark ignition mode and in said homogeneous charge dual fuel transition mode; and

a control system adapted to transfer engine operation between said spark ignition mode and said homogeneous charge dual fuel transition mode and between said homogeneous charge dual fuel transition mode and said premixed charge compression ignition mode.

29. The engine of claim 28, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of said first fuel for igniting a premixed charge of said second fuel and air.

30. The engine of claim 28, wherein said control system is further adapted to cause said fuel delivery system to deliver a post-ignition injection of said first fuel into said combustion chamber after a start of combustion of a premixed charge of said second fuel and air in said combustion chamber when in said premixed charge compression ignition mode to operate the engine in a post premixed ignition injection mode.

31. The engine of claim 28, wherein said control system is further adapted to cause said fuel delivery system to deliver an early pilot quantity of said first fuel prior to a start of combustion a premixed charge of said second fuel and air in said combustion chamber when in said premixed charge compression ignition mode.

32. The engine of claim 28, wherein said first fuel is one of diesel fuel, kerosene and gasoline and said second fuel is one of natural gas and propane.

33. A method of operating an internal combustion engine in a plurality of modes for engine operation and transferring operation between the plurality of modes, comprising the steps of:

operating the engine in a spark ignition mode;

operating the engine in a premixed charge compression mode; and

operating the engine in a homogeneous charge dual fuel transition mode when transferring engine operation between said spark ignition mode and said premixed charge compression ignition mode.

34. The method of claim 33, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of a first fuel for igniting a premixed charge of fuel and air.

35. The method of claim 33, further including the step of delivering a post-ignition injection of a first fuel into a combustion chamber of the engine after a start of combustion of a premixed charge of a second fuel and air in the combustion chamber when in said premixed charge compression ignition mode to operate the engine in a post premixed ignition injection mode.

36. The method of claim 33, further including the step of delivering an early pilot quantity of a first fuel into a combustion chamber of the engine prior to a start of combustion of a premixed charge of a second fuel and air in said combustion chamber when in said premixed charge compression ignition mode.

37. The method of claim 33, further comprising the steps of:

providing a combustion chamber and an intake system for providing intake air and a second fuel to said combustion chamber, said intake system including a throttle valve for controlling the intake flow of at least one of intake air and a premixed charge of intake air and said second fuel;

operating the engine in said spark ignition mode with said throttle valve partially closed to restrict said intake flow into said combustion chamber, said premixed charge of said second fuel and air having an equivalence ratio greater than 0.5;

decreasing a quantity of said second fuel in said premixed charge while increasing a quantity of a first fuel delivered into said combustion chamber in a manner

to maintain engine torque at a substantially constant level and to reduce the equivalence ratio of said premixed charge to less than 0.5;

opening said throttle valve to increase said intake flow;

terminating the flow of said first fuel into said combustion chamber to transfer the engine to said premixed charge compression ignition mode.

38. The method of claim 37, wherein said steps of opening said throttle valve to increase said intake flow and terminating the flow of said first fuel occur simultaneously while maintaining said total delivered fuel energy at a substantially constant level.

39. The method of claim 38, wherein said step of opening said throttle valve to increase said intake flow approximately doubles a total amount of second fuel delivered to the combustion chamber.

40. The method of claim 37, wherein the step of decreasing a quantity of said second fuel in said premixed charge while increasing a quantity of the first fuel delivered into said combustion chamber continues until said second fuel and said first fuel each contribute about 50% of the total delivered fuel energy.

41. The method of claim 37, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of said first fuel for igniting a premixed charge of said second fuel and air.

42. The method of claim 33, further comprising the steps of:

providing a combustion chamber and an intake system for providing intake air to said combustion chamber, said intake system including an intake port and a throttle valve for controlling intake air flow;

delivering fuel into one of said intake port and said combustion chamber at a predetermined flow rate;

operating the engine in said spark ignition mode with said throttle valve partially closed to restrict said intake air flow to said intake port, said fuel and said

intake air mixing to form a premixed charge having an equivalence ratio greater than 0.5;

opening said throttle valve to increase said intake air flow while maintaining said predetermined fuel rate substantially constant to reduce the equivalence ratio of said premixed charge to less than 0.5 to place the engine in said premixed charge compression ignition mode.

43. The method of claim 42, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of fuel for igniting said premixed charge of fuel and air.

44. The method of claim 33, further including the steps of:

providing a premixed charge of a second fuel and air in a combustion chamber of the engine;

while operating in a spark ignition mode, decreasing a quantity of said second fuel in a premixed charge of fuel and air while increasing a quantity of a first fuel delivered into said combustion chamber in a manner to maintain an engine torque at a substantially constant level to transfer to said homogeneous charge dual fuel transition mode;

delivering an early pilot quantity of said first fuel prior to a start of combustion in said combustion chamber when in said homogeneous charge duel fuel transition mode and increasing said early diesel pilot quantity of said first fuel sufficiently to cause the start of combustion to occur prior to the delivery of said first fuel to operate the engine in a premixed charge compression ignition mode.

45. A method of operating an internal combustion engine in a plurality of modes for engine operation and transferring operation between the plurality of modes, comprising the steps of:

providing a combustion chamber and an intake system for providing intake air and a second fuel to said combustion chamber, said intake system including a throttle

valve for controlling the intake flow of at least one of intake air and a premixed charge of intake air and said second fuel;

operating the engine in a spark ignition mode with said throttle valve partially closed to restrict said intake flow into said combustion chamber, said premixed charge of a second fuel and air having an equivalence ratio greater than 0.5;

decreasing a quantity of said second fuel in said premixed charge while increasing a quantity of a first fuel delivered into said combustion chamber in a manner to maintain engine torque at a substantially constant level and to reduce the equivalence ratio of said premixed charge to less than 0.5;

opening said throttle valve to increase said intake flow;

terminating the flow of said first fuel into said combustion chamber to place the engine in a premixed charge compression ignition mode.

46. The method of claim 45, wherein said steps of opening said throttle valve to increase said intake flow and terminating the flow of said first fuel occur nearly simultaneously while maintaining said total delivered fuel energy at a substantially constant level.

47. The method of claim 45, wherein said step of opening said throttle valve to increase said intake flow approximately doubles a total amount of second fuel delivered to the combustion chamber.

48. The method of claim 45, wherein the step of decreasing a quantity of said second fuel in said premixed charge while increasing a quantity of a first fuel delivered into said combustion chamber continues until said second fuel and said first fuel each contribute about 50% of the total delivered fuel energy.

49. The method of claim 45, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of said first fuel for igniting a premixed charge of said second fuel and air.

50. A method of operating an internal combustion engine in a plurality of modes for engine operation and transferring operation between the plurality of modes, comprising the steps of:

providing a combustion chamber and an intake system for providing intake air to said combustion chamber, said intake system including an intake port and a throttle valve for controlling intake air flow;

delivering fuel into one of said intake port and said combustion chamber at a predetermined flow rate;

operating the engine in a spark ignition mode with said throttle valve partially closed to restrict said intake air flow to said intake port, said fuel and said intake air mixing to form a premixed charge having an equivalence ratio greater than 0.5;

opening said throttle valve to increase said intake air flow while maintaining said predetermined fuel rate substantially constant to reduce the equivalence ratio of said premixed charge to less than 0.5 to place the engine in a premixed charge compression ignition mode.

51. The method of claim 50, wherein said spark ignition mode includes a liquid spark comprising a pilot quantity of fuel for igniting said premixed charge of fuel and air.

52. A multi-mode internal combustion engine capable of operating in a plurality of modes for engine operation, comprising:

an engine body;

a combustion chamber formed in the engine body;

an intake air system for delivering intake air to said combustion chamber, said intake air system including an intake port and an intake valve for controlling flow of one of air and a mixture of air and fuel through said intake port;

a fuel delivery system mounted on said engine body for supplying fuel for combustion in said combustion chamber;

a spark ignition means for initiating a start of combustion when operating in a spark ignition mode;

a variable valve timing system for varying a timing of closing of said intake valve;

a control system for controlling said variable valve timing system to, at least one of:

transfer engine operation from said spark ignition mode to a premixed charge compression ignition mode by adjusting said timing of said closing of said intake valve to increase an effective compression ratio; and

transfer engine operation from said premixed charge compression ignition mode to said spark ignition mode by adjusting said timing of said closing of said intake valve to decrease an effective compression ratio.

53. A method of operating an internal combustion engine capable of operating in a plurality of modes for engine operation and transferring operation between the plurality of modes, comprising the steps of:

delivering intake air to a combustion chamber of the engine, said intake air system including an intake port and an intake valve for controlling flow of one of air and a mixture of air and fuel through said intake port;

supplying fuel for combustion in said combustion chamber;

providing a spark ignition means for initiating a start of combustion when operating in a spark ignition mode;

performing at least one of: i) transferring engine operation from said spark ignition mode to a premixed charge compression ignition mode by adjusting said timing of said closing of said intake valve to increase an effective compression ratio; and ii) transferring engine operation from said premixed charge compression ignition mode to said spark ignition mode by adjusting said timing of said closing of said intake valve to decrease an effective compression ratio.